Raytheon

Customer Success Is Our Mission

ROBOTIC HANDS AND ARMS

Developed by Raytheon SARCOS
and
SARCOS (Sterling)

Don McMonagle

Defining the Servicing Task/Tools

Raytheon
Missile Systems

Evolution of Human-Robotic Trades

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Missile Systems

Human Risk

- Orbital Debris in Some Orbits

Robotic Dexterity

- Improved Sensors/Servos/Actuators

Virtual Presence

- Improved Situation Awareness thru Cameras/Sensors/Communications

Raytheon SARCOS Bio Robotics Systems Developed and in Use

Raytheon Missile Systems

Playback Robots • Humanoids – Disney, more than 100 produced, up to 52 DOFs, 20 yrs. in operation • Dinosaurs – Jurassic Park The Ride, Universal Studios, 16 robots produced, up to 27 DOFs, 13 yrs. in op. in water • Bellagio Hotel VectorJet Fountains, 225 produced, 5 DOFs, 11 yrs. in op. - Largest Robot 700,000 lbs and >1100 DOF total • NASA Space Suit Tester • Animals (Ballys, Buffalo Bills, Universal Studios)	**XOS – Exoskeletal Robots** • XOS-1, Full Body exoskeleton, DARPA, 1 produced, 24 DOFs • XOS-2, Full Body exoskeleton, DARPA and US Army, 24 DOFs, (under development)
Teleoperated Robots • Dextrous Arm (DA) – Master and Slave, 15 produced, 10 DOFs each – Research and operation in hazardous environments • GRLA – Large scale version of the DA • TOPS – Master and Slave, 1 produced, 22 DOFs each • Ford Auto Show/Carnegie Science Center MC, 3 produced, up to 39 DOFs	**UGVs** • TRUE (wheeled+track/modular appendages), DARPA • TRUE quiet • MDMR Snake, DARPA, 11 DOFs + actuated cameras
Artificial Intelligence Research • Dextrous Arm (Balancing and Juggling), 10 DOFs • DB1 (Balancing, Juggling, Air Hockey), ATR Japan, 34 DOFs • DB2 (Walking Humanoid), ATR, CMU, 43 DOFs • Primus – Humanoid Head, 4 produced, 7 DOFs	**Artificial Limbs** • Utah Artificial Arm, more than 3000 produced • AdVAntage Prosthetic Arm, 20 produced
Virtual World Interfaces • UniPORT (unicycle system), 4 produced, 3 DOFs • TreadPORT (variable inclination treadmill with body push-pull mechanism), 3 produced, 5 DOFs • Individual Soldier mobility System (ISMS), 1 produced, 10 DOFs	**Robotics Key Technologies** • Servo-valves • Actuators (hydraulic, pneumatic, electric) • Control and Sensor Networks • MEMS sensor networks (strain, multi-axis strain, rotation)

***NOTE: DOFs = Degrees of Freedom. Each DOF is a movement**

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Sarcos Robotic Hands

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Systems/History	Mtl.	Clients/Sponsor	Applications	Comment	Power Source/Actuation
Prosthetic Hands - Hooks & Hands 1 DOF (Installed on 1 DOF arms)	Metals and Composites	NIGMS, Veteran's Administration	Amputees	Dexterity, weight, cost, manufacturability	Body Power, and Electric
Utah/MIT Dextrous Hand (16 DOFs, 32 Actuators and 48 sensors) also Master	Metals and Polymers	ONR	R&D in dexterous manipulations	Very high bandwidth control	Electro-pneumatic
NAVY Teleoperation Hand (TOPS)	Metals and Polymers	NOSC	Underwater Teleoperation	High Performance Force Reflecting Teleoperation	Electro-hydraulic with tendons
DA and GRLA - Hand (2 Jaw gripper, 1 DOF and 2 DOF Thumb) on 7 DOF arm	Metals	AT&T, Version for GRLA (Hydro-Quebec)	Underwater Teleop., High Power lines Maint. & R&D	High Fidelity Force Reflecting Teleoperation	Electro-hydraulic
Morph Hand (Parallel jaw gripper 1 DOF with 1 DOF swivel tip and 2 DOF Thumb)	Metals	Govt.	Underwater Teleop. and R&D	High Fidelity Force Reflecting Teleoperation	Electro-hydraulic
Plate Hands (4 fingers 1 DOF ea., and 1 Thumb 2 DOF)	Metals	ATR	Humanoid Robots R&D	Low cost,, finger articulations are coupled	Electro-pneumatic
Advanced Hand Concept	Metals, Polymers	IR&D funded	Dexterous Manipulation	Designed to handle complex objects	Electro-pneumatic, Electric or hydraulic

TOPS - Teleoperated Humanoid Robot (SARCOS 1st)

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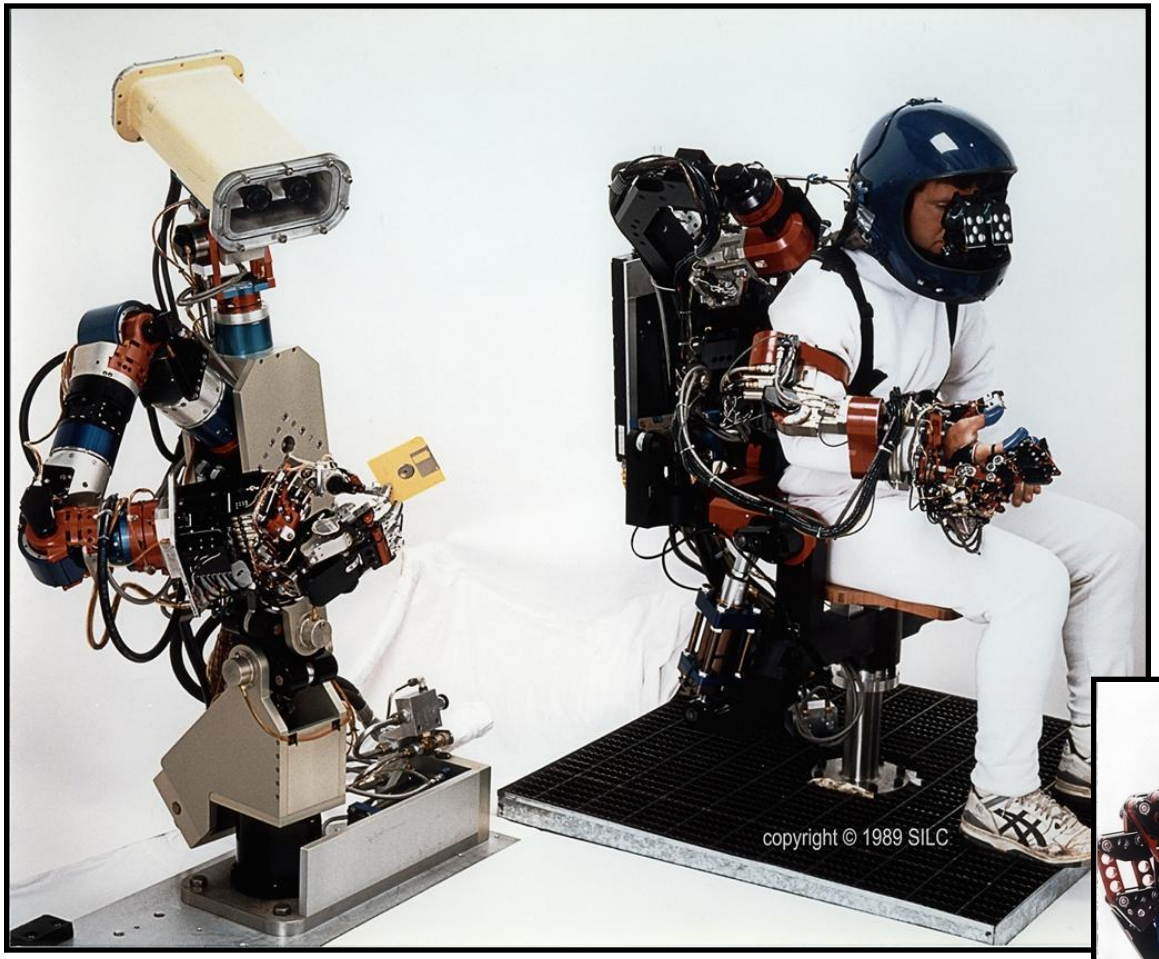
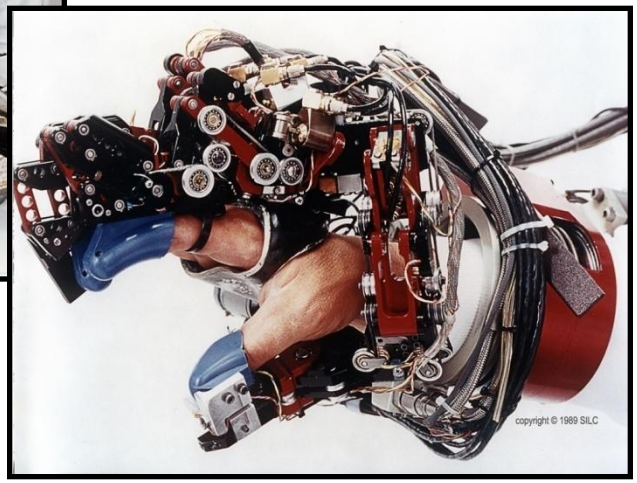


COMPREHENSIVE

SYSTEM

- **MANY DEGREES OF FREEDOM**
- **VISION**
- **TOUCH**



THE UTAH / MIT DEXTROUS HAND (UMDH)

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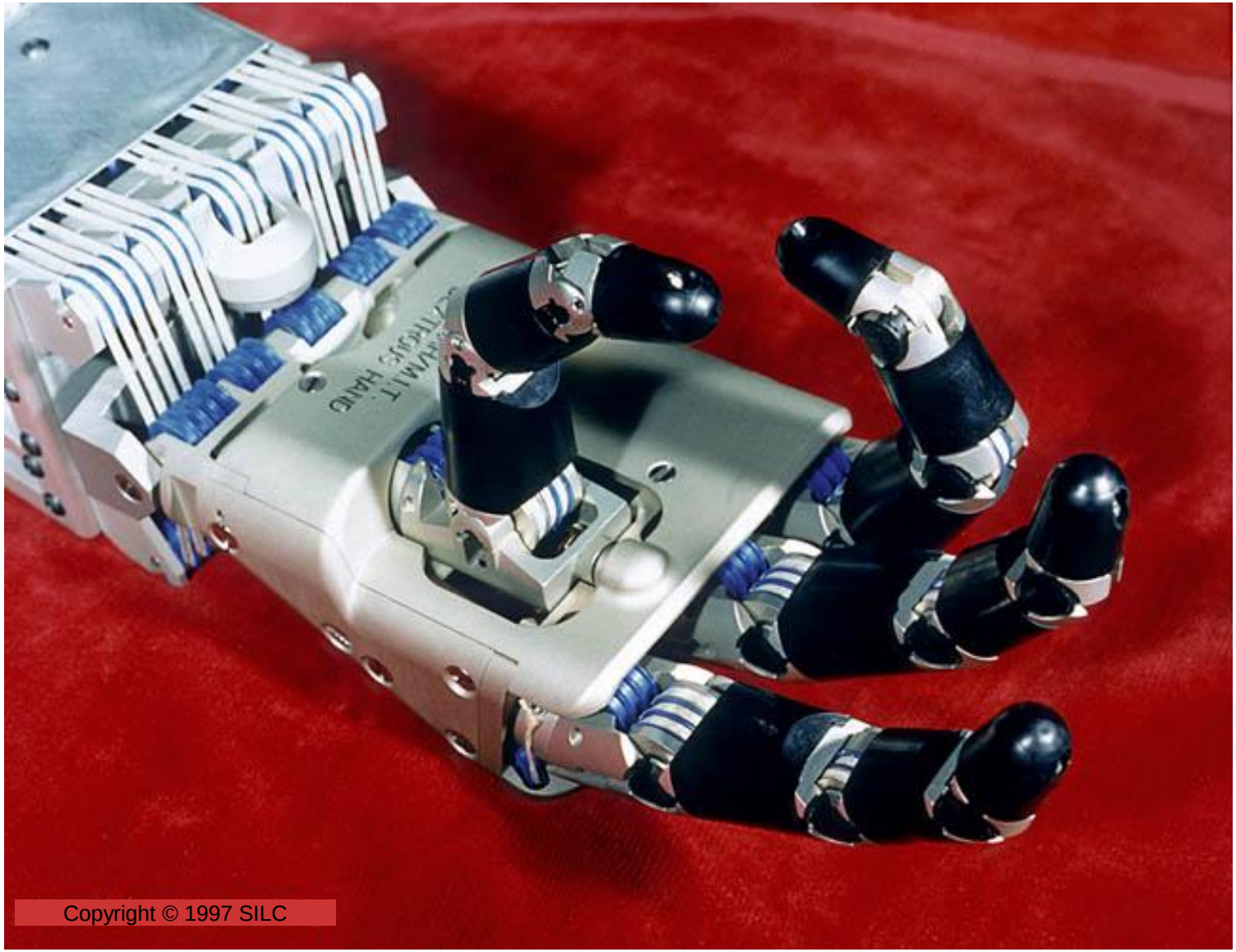

THE UTAH / MIT DEXTROUS HAND (UMDH)
16 Degrees of Freedom

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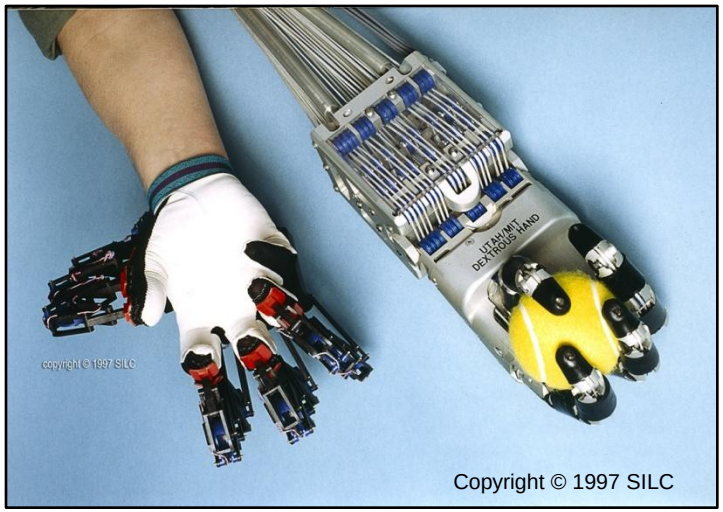
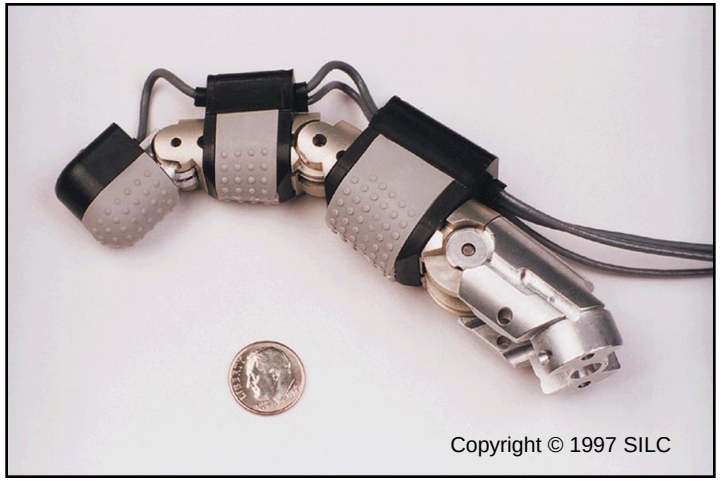
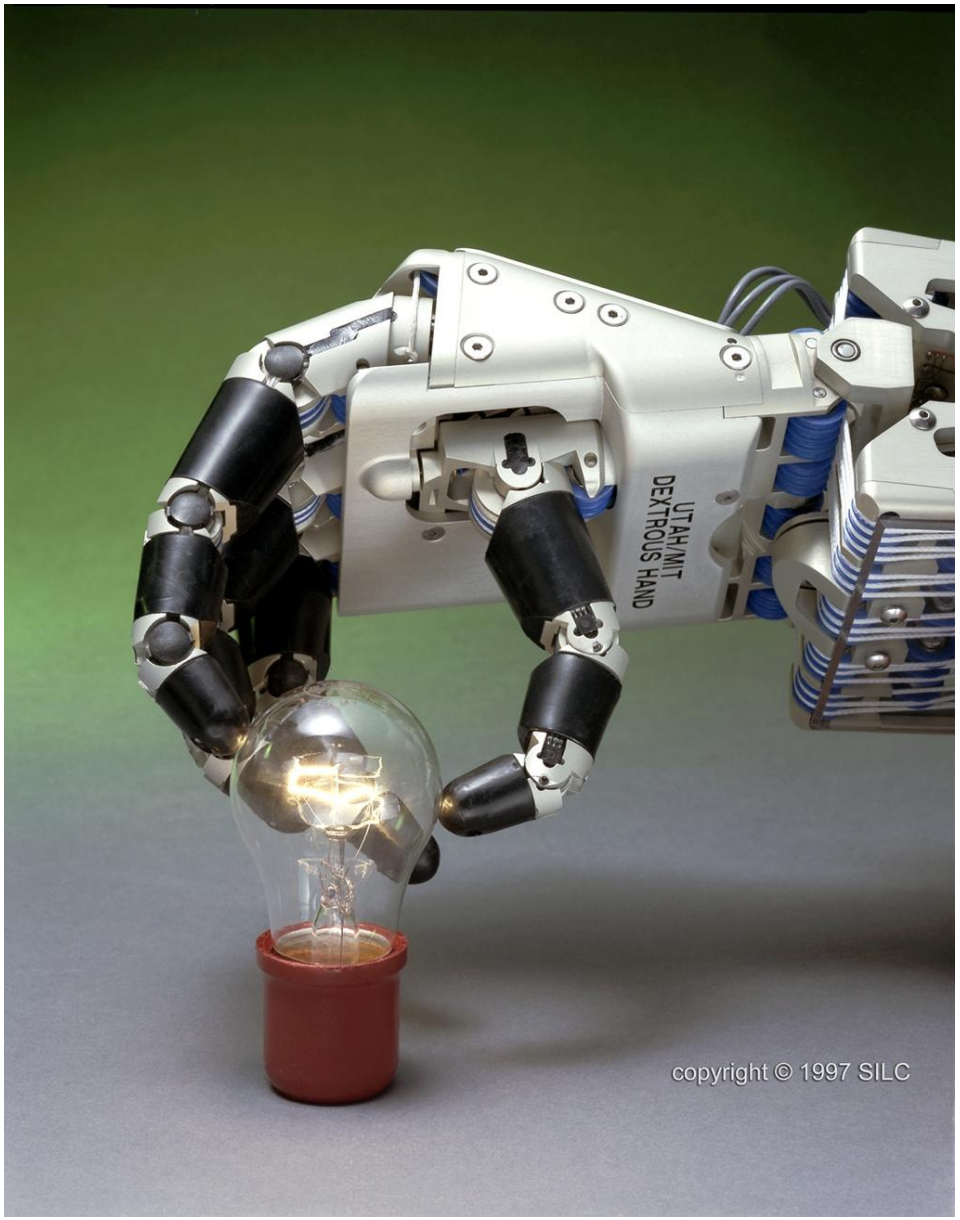




Tactile Sensors for NASA

“Approved for public release, distribution unlimited”



DB 2.2 HAND (6 DOF)

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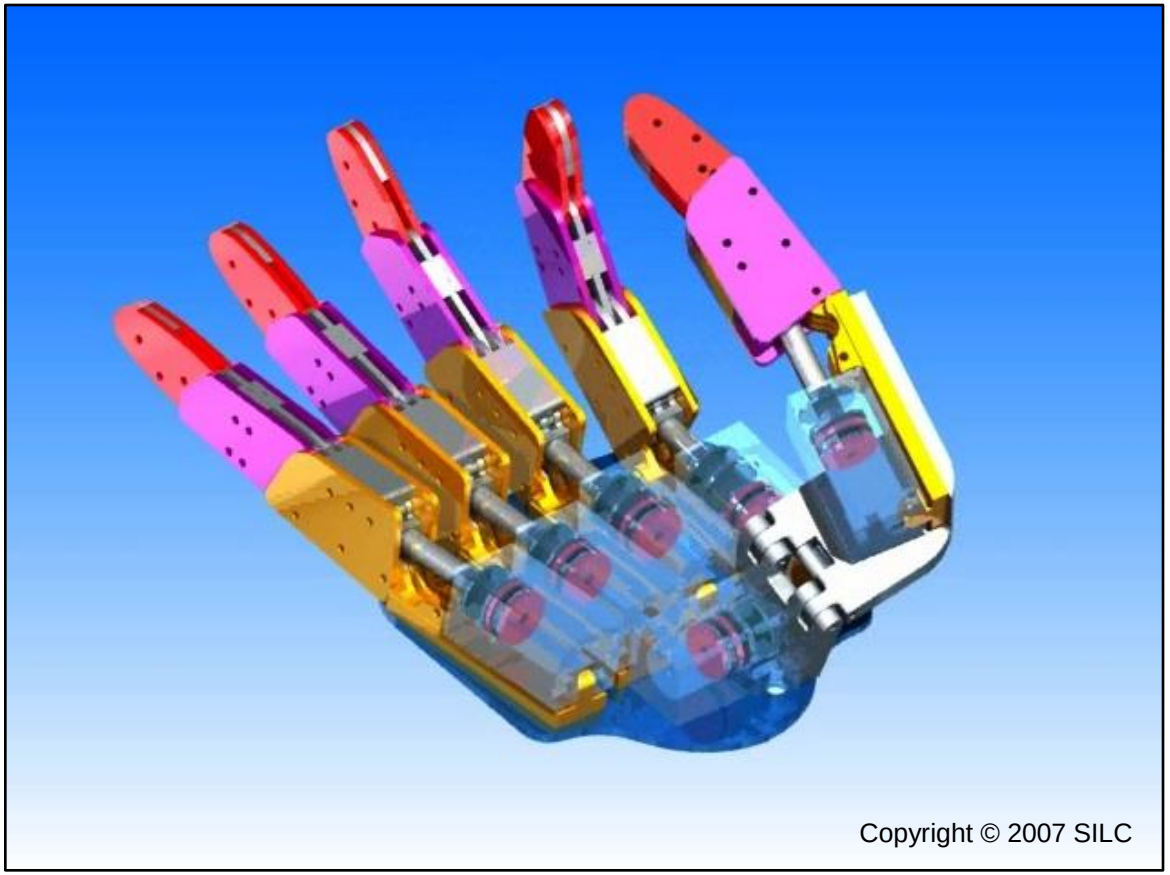

DB 2.2 HUMANOID PLATE-BASED HAND

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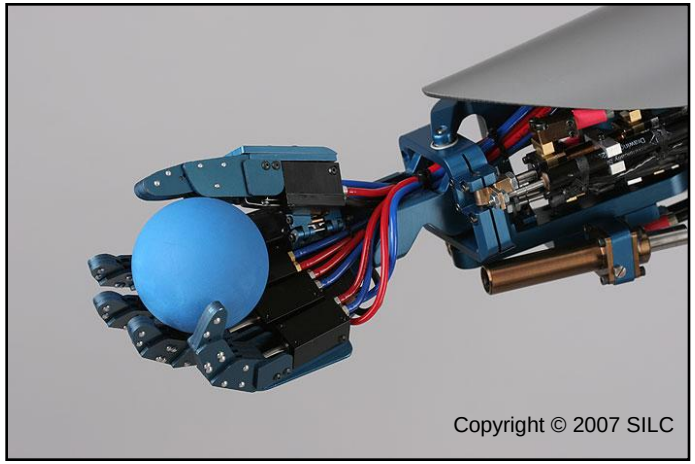

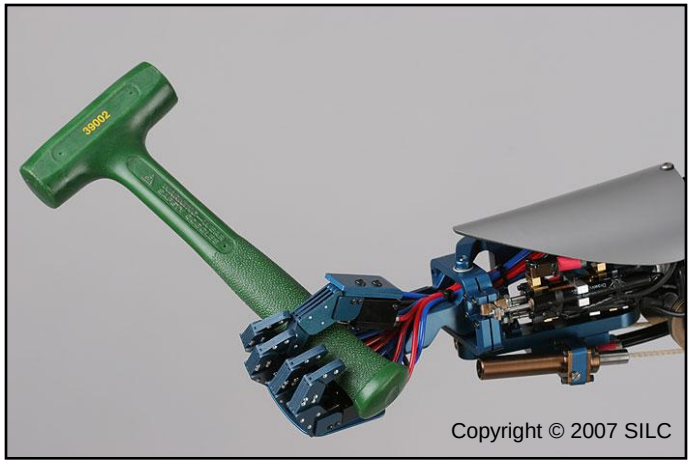

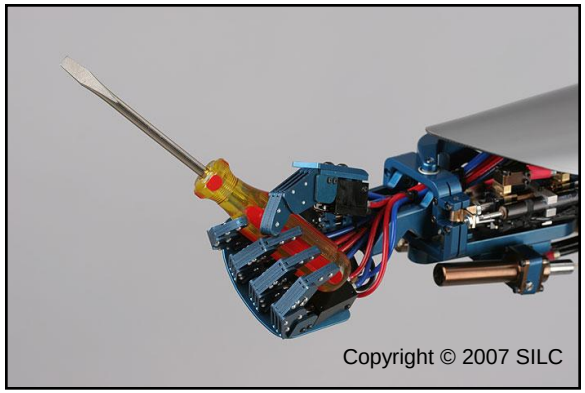

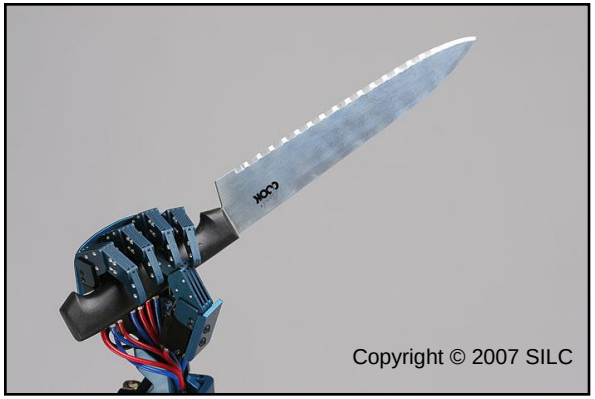

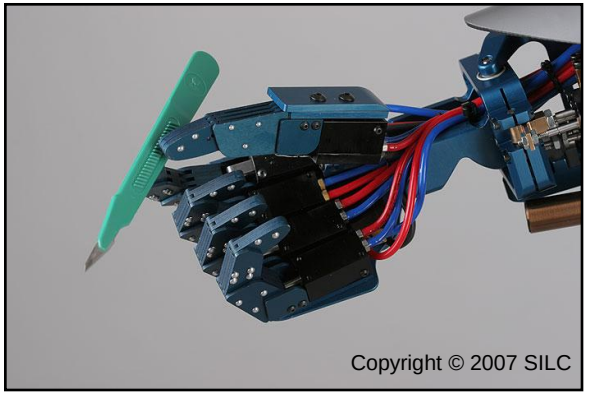

SPLIT HOOK & THUMB(3 DOF) - Used on DA and GRLA

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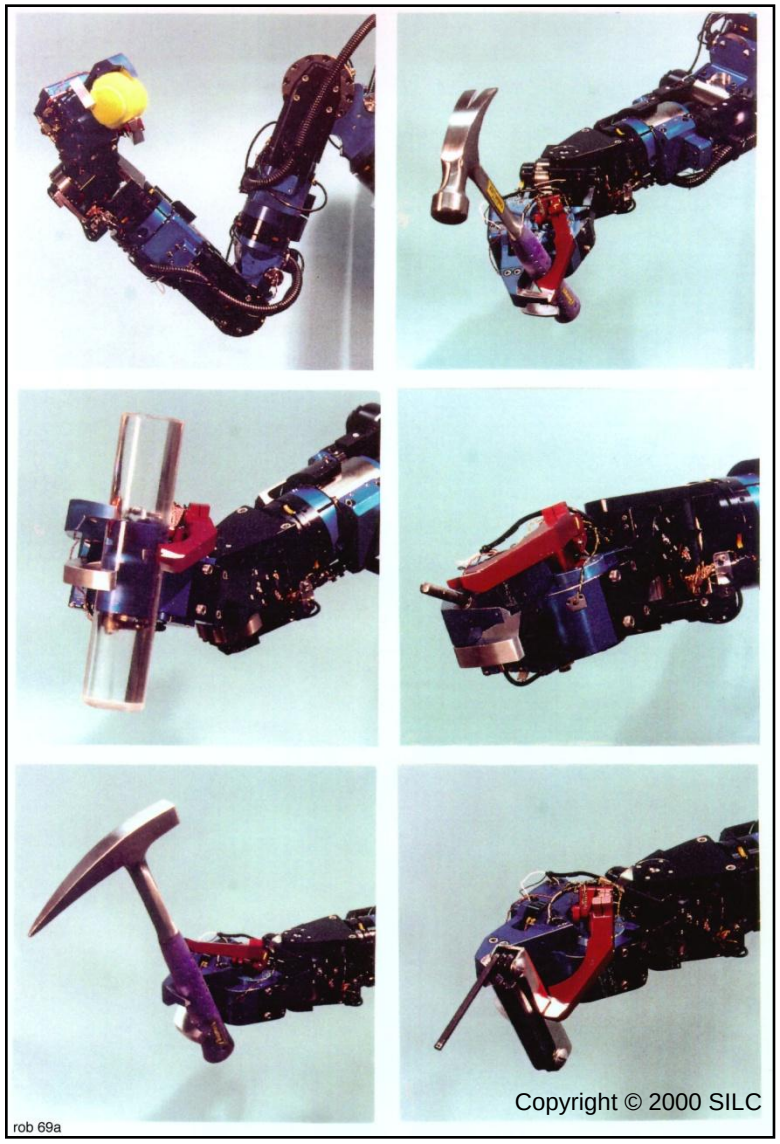

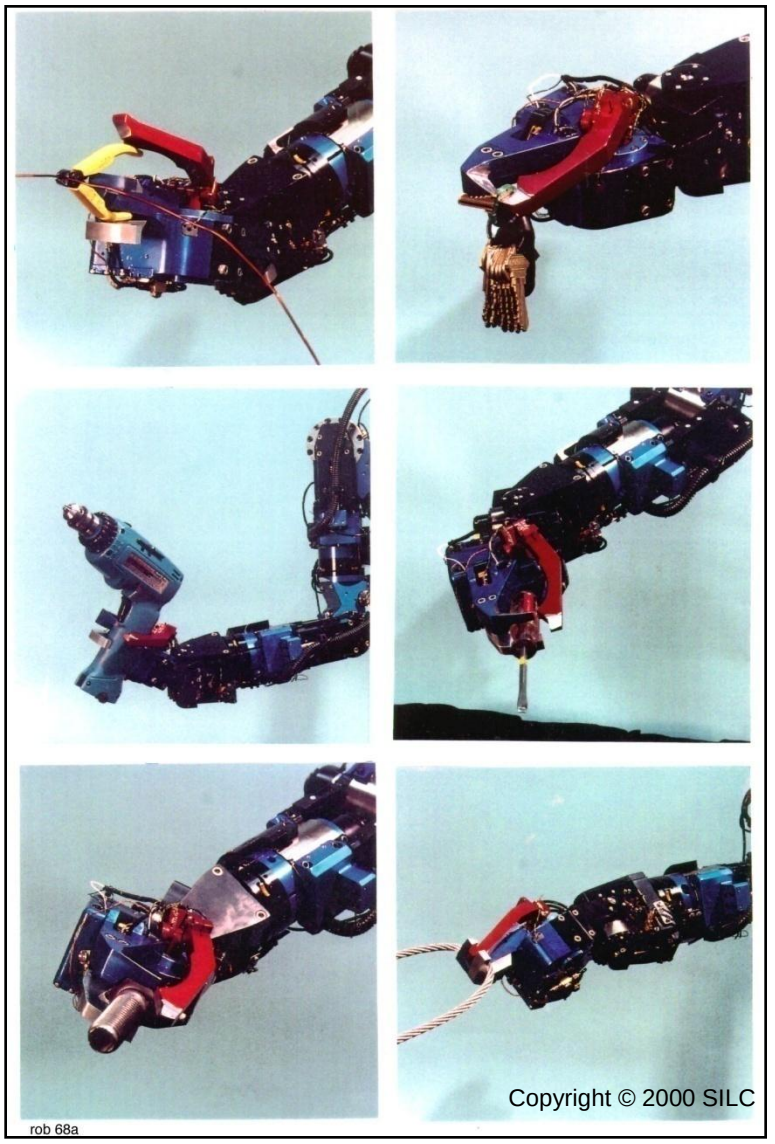

MACHINE DEXTERITY

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Behavior Based Design Approach

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- Define Desired Objectives
- Quantitative Performance Criteria
  - Structural Smoothness
  - Structure/actuator stability assurance
  - Static force accuracy
  - Load movement grace
  - Strength
  - Saturation avoidance
  - Response of the load to insults – carried load
  - Response of the structure to insults – passive impedance
  - Force generation quickness – application of force

Control Approach

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- Seven Levels of control subdivided into three categories:
- Variable Control
  - Command Production
  - Variable Autonomic
- Intrinsic Control
  - Fixed Autonomic
  - Servo Control
  - Passive Intrinsic Properties
- Power Systems
  - Actuation Systems
  - Energy Storage Systems

TELEOPERATED ROBOTS (I)

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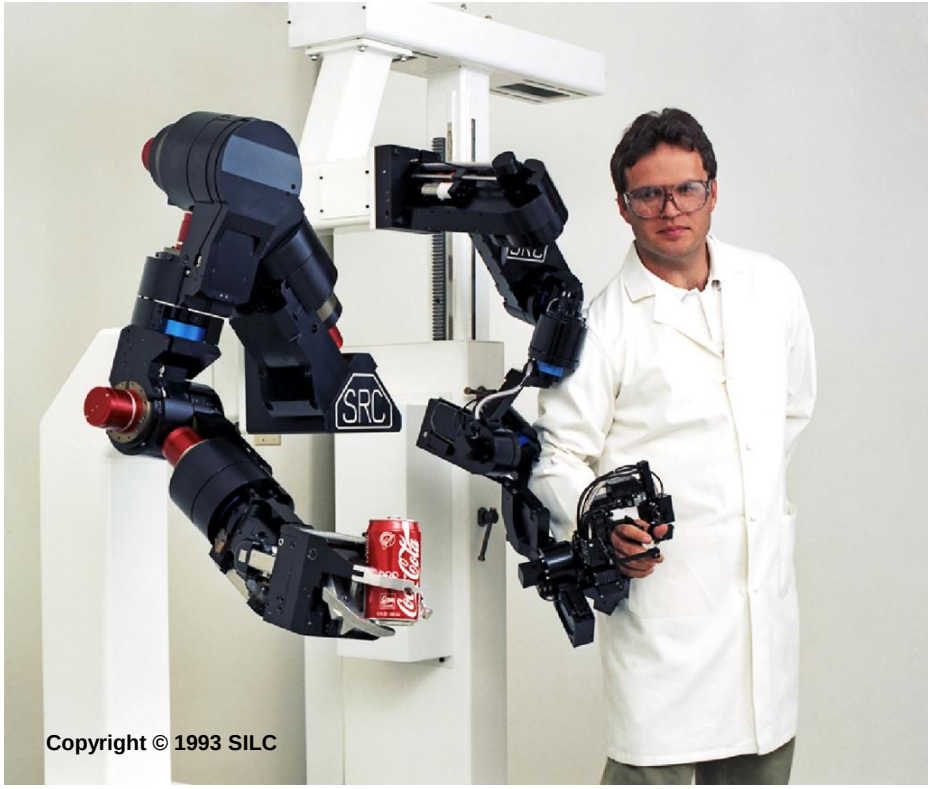
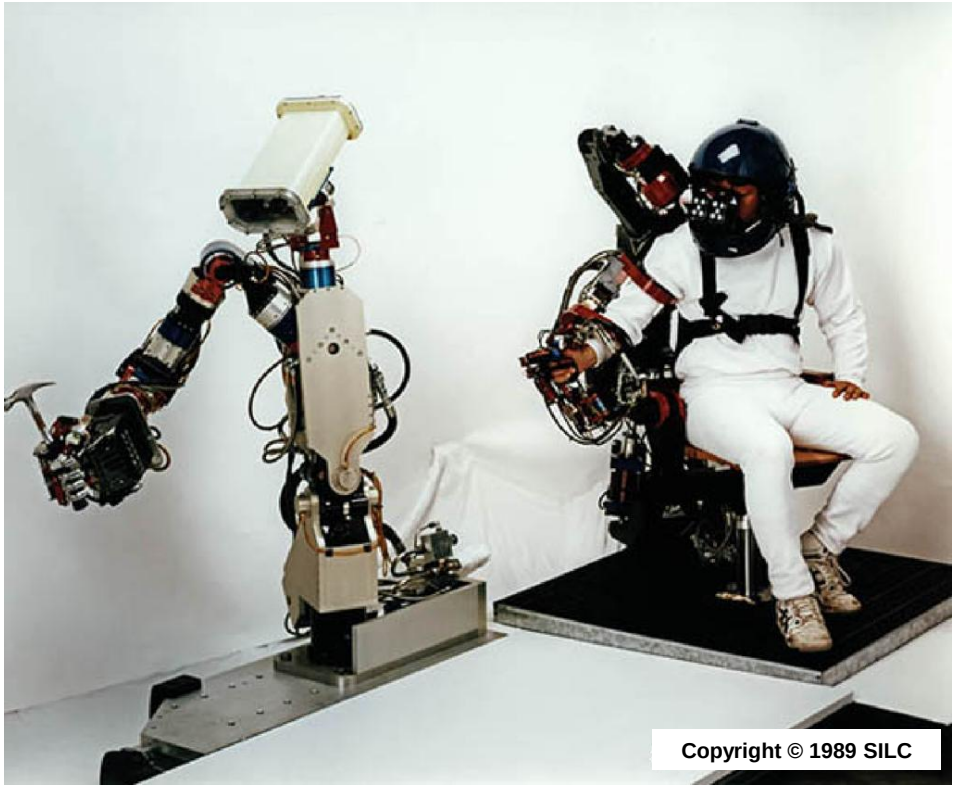
DA Force-reflecting Master-Slave – 15 Systems Produced



TOPS – Master-Slave System



- Examples of teleoperated robots developed and built by Sarcos, including: (i) the Dextrous Arm (DA) Slave and Master (10 DOFs each) – High fidelity force-reflecting teleoperated robot; and (ii) the TOPS force-reflective master and slave robot with hand, arm, torso, & head (hydraulic) (22 DOFs each).
- The DA-DAM was developed for a broad range of applications where superior dexterity and extended physiologic proprioception must be achieved to carry out operations in environments that are inhospitable to people and where the tasks to be done are either unknown or ill-defined.
- In its original configuration the DA Slave was developed to perform underwater tasks at depths down to 20,000 feet below sea level (over 20 times deeper than humans can dive).

ROBOTS for R&D in AI and Legged Locomotion

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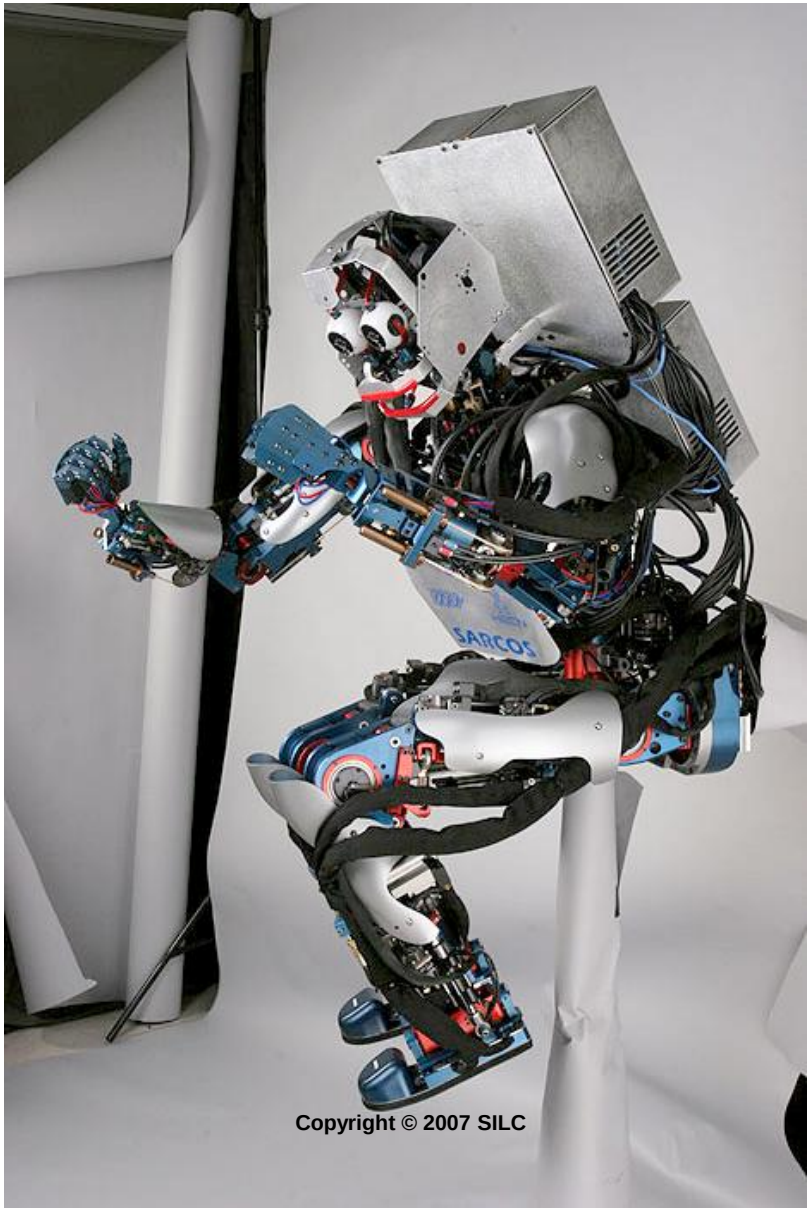
43 DOFs
DB2
Humanoid
3 Systems
Produced



EXOSKELETON – WEARABLE ROBOTS

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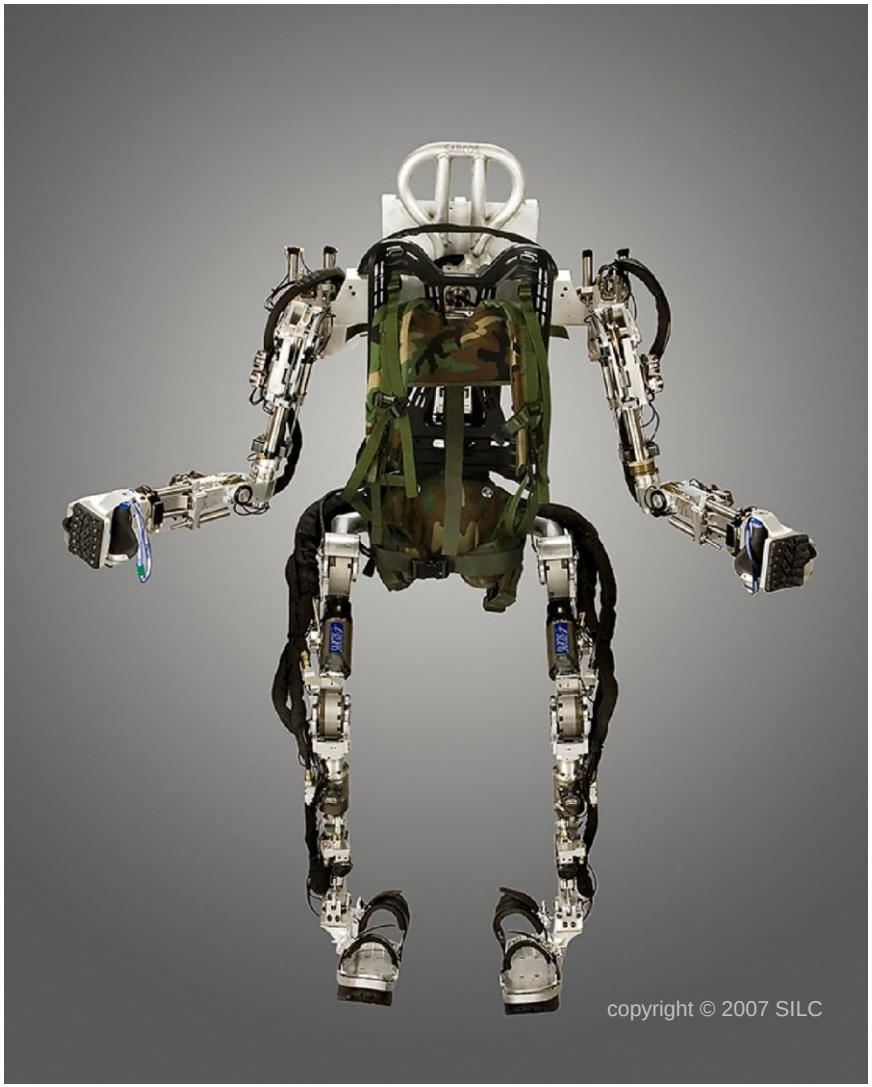
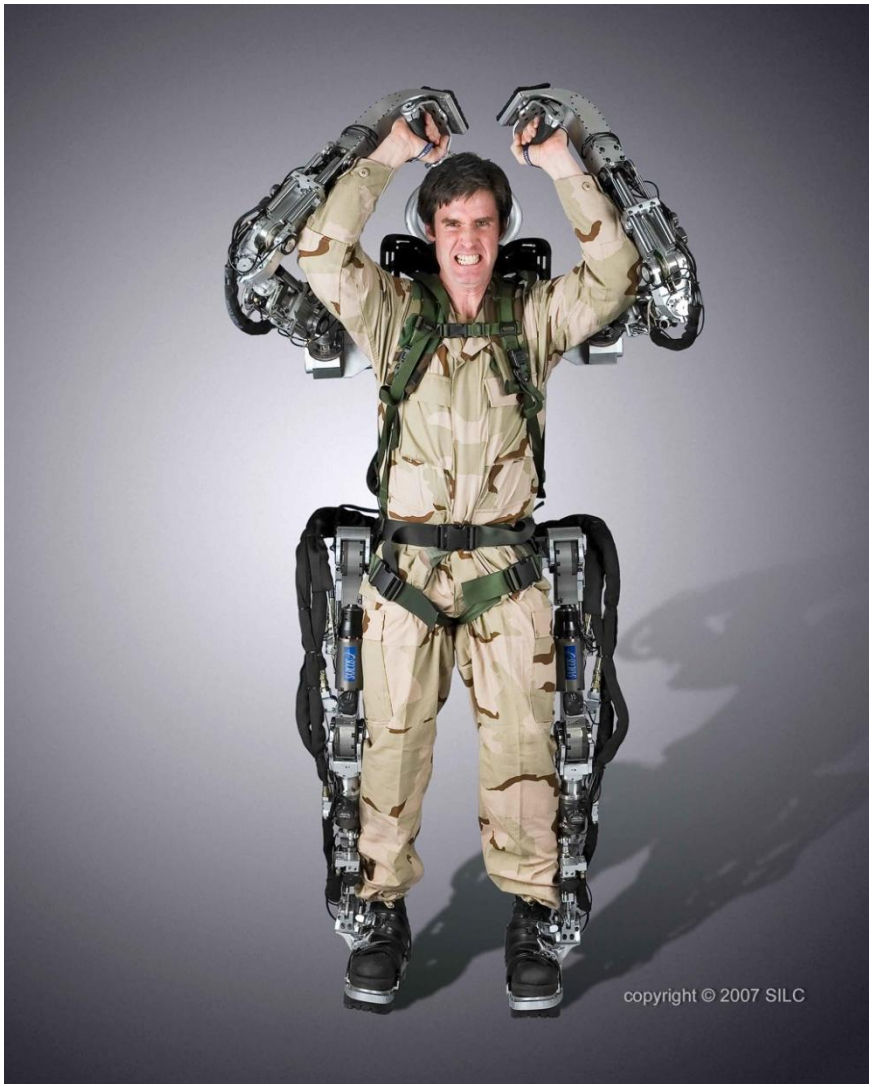
24 DOFs - XOS-1 – 3 Versions Produced



XOS-1 with Operator



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